New Perspectives on Fe-Ti±V Mineralization in the Ślęża-Kunów Area, SW Poland: Findings from the SEMACRET Project

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Abstract. The SEMACRET Horizon Europe project aimed to identify new mineralized zones through the application of innovative geophysical and geochemical methods. The northern part of the Central Sudetic Ophiolite, specifically the Ślęża Massif and its surroundings, was selected as the reference site. On the surface of Ślęża Mountain, four elongated, southwest-oriented lenses enriched in iron, titanium, and locally vanadium were delineated. Similar mineralized bodies were identified both at the surface and at depth on Kunów Hill. In both areas, the mineralized zones are composed of diallagic gabbros and ferro-gabbros with ophitic textures, indicating a magmatic origin of the Fe-Ti-V mineralization. Microscopic analyses reveal that the mineralization is predominantly monomineralic, consisting mainly of ilmenite with minor amounts of magnetite. Investigations of two boreholes suggest that the mineralized zones can be interpreted as south- or southwest-dipping lenses and dikes of oxide gabbros and ferro-gabbros. These oxide-rich zones were delineated using aeromagnetic surveys, electrical resistivity tomography (ERT), and gamma spectrometry. Future exploration efforts, particularly diamond drilling, should be concentrated in the eastern slopes of the Ślęża Mountain and Kunów area and guided by high-resolution geophysical surveys.

1 Introduction

The SEMACRET project aims to advance sustainable exploration of Critical Raw Materials (CRMs) essential for the green transition in the EU, ensuring a secure and continuous supply for its industries. The research focuses on orthomagmatic sulfide and oxide ore deposits, which host a variety of CRMs, including platinum-group metals (PGMs), copper, cobalt, nickel, vanadium, and titanium.

Currently, only one orthomagmatic sulfide deposit (Kevitsa Ni-Cu-PGE-Co, Finland) and one orthomagmatic oxide deposit (Kemi Cr, Finland) are in production within the EU. However, mafic and ultramafic complexes, which have the potential to host such deposits, are present in several European regions, including Portugal (e.g., Beja Igneous Complex), Spain (e.g., Aguablanca deposit), the Czech Republic (e.g., Staré Ransko deposit), Denmark (e.g., Skærgård deposit, Greenland), and Poland (Central Sudetic Ophiolite).

The primary objective of the SEMACRET project in southwestern Poland was to identify new concealed areas for CRM exploration by integrating advanced geophysical methods with geochemical and petrological investigations.

The Ślęża ophiolite was chosen as a reference site because it is the largest exposed section of the Central Sudetic ophiolite and retains a nearly complete, typical ophiolite pseudo-stratigraphic sequence (Kryza and Pin, 2010). From base to top (south to north), the sequence includes: (1) serpentinized peridotites – Gogołów-Jordanów, (2) pyroxene- and amphibole-rich rocks (ultramafic cumulates; Gogołów-Jordanów), (3) metagabbros (mainly mafic cumulates – Ślęża and Kunów), (4) diabases and metabasalts (likely representing sheeted dykes and lavas, including rare occurrences of pillowed basalts; Gozdnica), and (5) dark metacherts containing radiolaria. The Kunów massif (NE of the Ślęża mountain) is an example of the mafic plutonic sequence of the Ślęża ophiolite under sedimentary cover.

The Ślęża and Kunów regions are predominantly composed of gabbro, with occurrences of serpentinized peridotite. Within the plutonic section of the Ślęża ophiolite, the gabbros are generally medium- to coarse-grained and frequently display an igneous ophitic texture. These rocks exhibit a diverse range of textural features, including ophitic, subophitic, porphyritic, and glomeroporphyritic structures, along with significant variations in grain size and compositional layering (Wahed and Mierzejewski 1998). The primary mineral assemblage of the gabbro consists of partially uralitized clinopyroxene and saussuritized plagioclase, with original anorthite content varying between 50% and 70%, accompanied by minor amounts of opaque minerals. Additionally, secondary minerals formed through post-magmatic or metamorphic alteration are present, including uralitic green amphibole (ranging from Mg-hornblende to actinolite), albite, sphene, epidote (zoisite), calcite, and chlorite. Key accessory minerals include apatite, ilmenite, titanite, magnetite, pyrite, and pyrrhotite.

The presence of ilmenite-bearing rocks within the Ślęża ophiolite was initially documented prior to World War II (Finck, 1928). However, only preliminary geological exploration was conducted at that time, and the area was deemed economically unviable. Detailed geological and geochemical surveys in the 1980s identified three primary zones of ilmenite mineralization within the Ślęża mountain (Jamrozik et al., 1988). Later studies confirmed the presence of titanium- and vanadium-rich mineralized outcrops within the area, with concentrations reaching up to 6.35 wt.% TiO_2 and 0.164 wt.% V_2O_5 (Niśkiewicz and Siemiątkowski, 1993, Jamrozik, 1989). At the same time, geophysical surveys identified a SW-NE oriented magnetic anomaly approximately 6 km long, extending from Strzegomiany village toward Kunów Hill, east of the Ślęża mountain. Analyses of gabbro samples from this area showed elevated levels of titanium and vanadium (4.92 wt.% and 0.154 wt.%, respectively) (Jamrozik, 1989). Later studies revealed multiple smaller, generally SW-NE- and W-E-oriented, lens-shaped outcrops of the ilmenite-bearing rocks on the Ślęża mountain (Wahed and Mierzejewski, 1998).

The mineralized zones are composed of diallagic gabbros with ophitic textures. Microscopic examinations indicate that it is essentially monomineralic—composed primarily of ilmenite with minor magnetite. Accessory minerals include rutile, pyrrhotite, pyrite, and chalcopyrite, with secondary minerals such as covellite and goethite also present. Ilmenite and magnetite occur in a dispersed form among rock-forming minerals, occasionally forming larger, intergranular aggregates. Grain size varies from very fine microscopic grains to 2–5 mm, with most grains ranging between 50–250 µm. The grains are typically xenomorphic to hypidiomorphic. Smaller grains often exhibit prismatic to needle-like shapes. Textural observations indicate that ilmenite-magnetite mineralization developed concurrently with the primary silicate minerals, clinopyroxene and plagioclase.

2 Methods

The primary objective of the field investigation was to characterize Fe-Ti±V mineralization within the plutonic assemblage of the Ślęża Massif, part of the Central-Sudetic ophiolite. To achieve this, geophysical surveys were conducted, including 12 geoelectrical tomography (ERT) profiles, three gamma-ray spectrometry profiles, and a magnetic survey, aimed at delineating the geophysical response associated with the mineralized rock basement. During the field tests, chemical composition analyss of the samples was conducted using portable X-ray fluorescence (pXRF). Based on the pXRF results, samples were selected for bulk-rock chemical testing and petrographic analysis. Samples of gabbro and metabasalt were collected from the Ślęża Massif, along with samples from Kunów Hill. A total of 20 samples from Mount Ślęża and 29 samples from Kunów Hill were analyzed to determine their bulk-rock chemical composition (Figure 1).

2.1 Geophysical surveys

The ERT surveys (12 profiles) were performed using 12-channel geoelectrical apparatus Terrameter LS, of Swedish company Abem Instrument AB. A gradient measurement system was used in the study with the 5 m and 10 m distance between measuring electrodes along 4 x 100 m and 4x200 m cables, giving 80 electrodes working simultaneously.

The UAV-based magnetic surveys were conducted to assess the feasibility of the method and optimize the methodology in accordance with the equipment and environmental conditions to enhance effectiveness. A total flight distance of 57.7 km was completed at the Kunów site. Three missions were executed over the same square grid with a 50 m line spacing, each covering a flight length of 5.4 km, at successive altitudes of 32 m, 52 m, and 77 m above ground level (a.g.l.). Additionally, ground-based gamma-ray spectrometry measurements were carried out along transects crossing Kunów Hill, with a sampling interval of 10 m (Figure 1, 2).

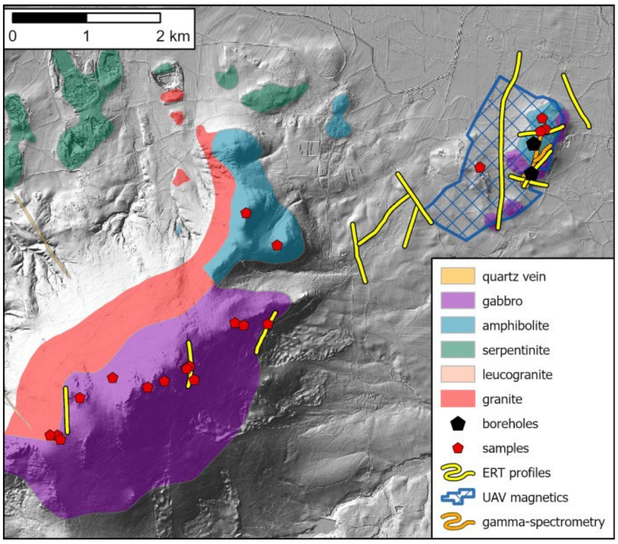

Figure 1. Location of samples, boreholes and geophysical surveys carried out in the reference site (geology after Gaździk 1957 and Trepka and Mierzejewski 1957)

2.2 Geochemical analysis

Olympus Vanta M Series XRF spectrometer was used to study composition of outcropping rocks in the field. Each sample was measured for 30 seconds per beam across three measurement beams, with multiple measurements taken per sample to ensure an accurate averaged composition due to the pinpoint nature of the method. The tests employed the "Soil Extra" mode to assess trace element content. The Olympus Vanta M Series XRF analyzed a broad set of elements, including Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Cs, Ba, La, Ce, Pr, Hf, Ta, W, Pt, Au, Hg, Pb, Bi, Th, and U. Particular focus was placed on the concentrations of titanium, vanadium, and iron, along with critical and valuable metals related to orthomagmatic deposits, such as nickel, cobalt, chromium, gold, and platinum group elements. In total, over 1200 pXRF analysis were performed in the area of ca. 12 km^2.

Three analytical methods were applied to study chemical composition of sampled rocks – XRF for main elements (SiO_2, Al_2O_3, TiO_2, MnO, Fe_2O_3, K_2O, Na_2O, CaO, MgO, P_2O_5, SO_3, Cl, and F), XRF for trace elements (As, Ba, Bi, Br, Ce, Co, Cr, Cu, Ga, Hf, La, Mo, Nb, Ni, Pb, Rb, Sr, Th, U, V, Y, Zn, Zr, Cd, and Sn), and ICP-MS for rare earth elements (Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Yb, Sc, Y, and Th). Chemical analyses were performed in the Chemical Laboratory of the Polish Geological Institute – National Research Institute in Warsaw, Poland.

3 Results

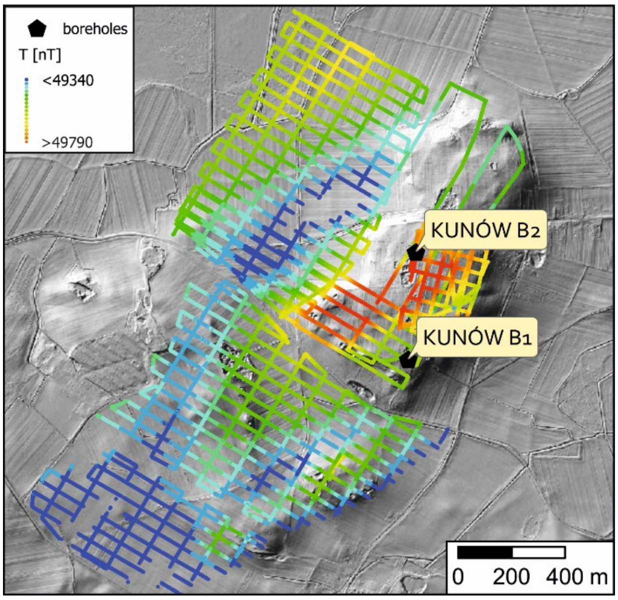

Figure 2. Map of Magnetic anomalies at Kunów hill.

Geochemical and geophysical investigations have identified multiple, small, ferro-gabbroic zones, each measuring a few tens of meters in length and a few meters in width, enriched in iron, titanium, and locally vanadium within the Ślęża Massif and the Kunów Hill. Magnetic survey showed set of strong, linear anomalies in the Kunów hill area (Figure 2). The B2 borehole is located at one of these anomalies. Magnetic image is confirmed with ERT results. Resistivity sections define the boundary between the basement rocks and the overlying Quaternary sedimentary cover while also revealing resistivity anomalies within the basement itself. This method demonstrated its effectiveness in determining approximate depth of the crystalline basement within the study area.

SEMACRET study showed that the mineralized ferro-gabbro from Ślęża contains as much as 5.6 wt. % TiO_2, 23.8 wt. % Fe_2O_3 and 1450 ppm vanadium. In the outcropping part of the Kunów area titanium contents are generally slightly lower (up to 5.5 wt. % TiO_2), whereas iron and vanadium contents are higher (27.8 wt. % Fe_2O_3 and 1600 ppm V). In both areas copper, nickel, cobalt and chromium concentration is generally very low, except one anomalous nickel-enriched sample from the eastern slope of the Ślęża Mountain.

Chemical analyses and portable X-ray fluorescence assays indicate that the highest concentrations of Fe-Ti±V mineralization occur in lens-shaped bodies with a southwest-northeast orientation. These bodies are spatially aligned in a linear pattern extending from the western slope of Mount Ślęża toward the gabbro outcrops at Kunów Hill. However, these mineralized zones are discontinuous, forming isolated lenses of gabbro with anomalously high Fe content rather than a continuous ore body. The results of the geophysical surveys suggest that these mineralized bodies may extend to greater depths within the investigated area.

Logging and sampling of two boreholes, Kunów B1 and Kunów B2, provided insights into the vertical extension of Fe-Ti±V mineralization down to a depth of ca. 100 meters below ground level. These boreholes intersected gabbro with varying textures, as well as multiple oxide-rich intervals ranging in thickness from less than 0.5 meters to nearly 2.0 meters. Portable X-ray fluorescence analysis of core samples identified elevated concentrations of iron, titanium, and vanadium in four oxide-rich intervals within the Kunów B1 borehole and six such intervals in the Kunów B2 borehole. Chemical analyses of three samples from the boreholes confirmed strong titanium and vanadium results (up to 4.77 wt. % TiO_2 and 1607 ppm V).

On the southeastern slope of Mount Ślęża, an ultramafic rock enriched in nickel has been identified. Geochemical analysis indicates that it contains 19.8 wt.% magnesium oxide (MgO), 14.3 wt.% ferric oxide (Fe_2O_3), and 0.19 wt.% nickel. The spatial distribution of this ultramafic body aligns closely with the results of an electrical resistivity tomography (ERT) survey, which reveals a diapir-like, very small (up to few meters in diameter) intrusion at shallow depths, characterized by a strong anomalous resistivity signal. To date, no petrographic studies have been carried out on rock samples from that location; however gabbro from adjacent area contain minor sulphide mineralization composed of pyrrhotite, chalcopyrite, pyrite and pentlandite.

3 Conclusions

The Ślęża area remains one of the most systematically studied and well-documented regions of the Central Sudetic Ophiolite. However, the application of advanced geophysical methods has demonstrated that further exploration could yield promising results, particularly in identifying deeper Fe-Ti±V mineralization and potential sulphide-bearing Ni-enriched zones. The most promising areas for future research include Kunów Hill, the eastern slopes of Mount Ślęża, and the region between Mount Ślęża and Kunów Hill, which may contain numerous small titanium-vanadium placer deposits. Future research should prioritize detailed field observations, a dense sampling grid, and the application of geophysical methods, including ERT, gamma and UAV magnetics. A critical raw materials perspective should also be incorporated, with ophiolitic sequences systematically analyzed for their nickel, cobalt, vanadium, scandium and platinum group element potential.

Acknowledgements

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